Focused Helium Ion Beam Nanofabrication by Near Surface Swelling

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The focused helium ion beam microscope is a versatile imaging and nanofabrication instrument with sub-10 nm resolution. Subsurface damage and swelling of substrates due to helium ion implantation is generally unwanted. However, these effects can also be leveraged for specific manipulation of substrates and materials. To explore this, we investigate focused helium ion beam induced swelling of bulk crystalline silicon and free-standing amorphous silicon nitride membranes using various irradiation strategies.

Several groups have explored advanced 3D nanofabrication using the nanoscale positioning accuracy and dose control of the helium FIB. For example, silicon substrates have been irradiated with helium ions to form raised lines with a half-pitch of 3.5 nm, and in the same work, concentric square and circular irradiations were used to create raised 3D pyramid and cone-shaped structures[1]. Focused helium ion irradiation and swelling of silicon substrates over broader areas has also been demonstrated as a method to deform supported structures, such as nanoporous aluminum oxide films, leading to the enlargement of the nanopores in the film due to the substrate-induced strain[2].

In this talk, we will demonstrate that the creation of near-surface voids due to helium ion implantation can be used to induce surface nanostructure and create subsurface nanochannels. By tailoring the ion dose and beam energy, the size and depth of the swollen features can be controlled. Swelling heights of several hundred nanometers are demonstrated and for the embedded nanochannels, void internal diameters down to 30 nm are shown. Potential applications include the engineering of texturized substrates and the prototyping of on-chip nanofluidic transport devices.

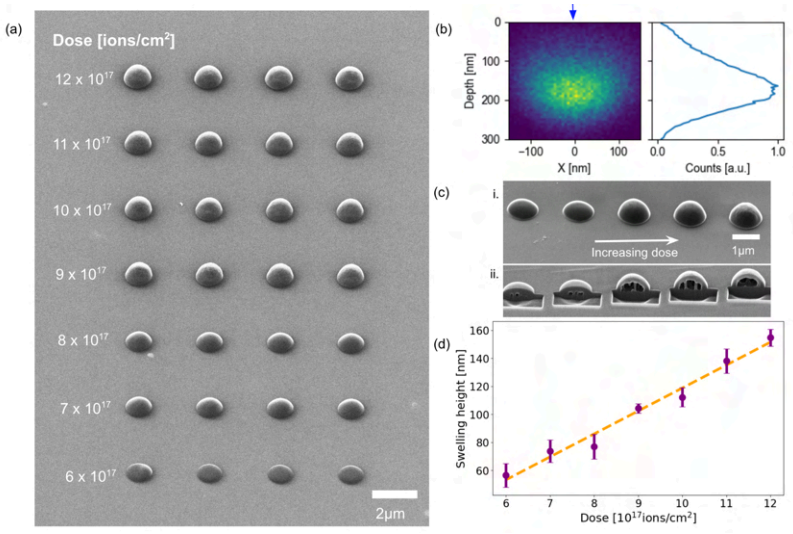

FIG. 1. Texturizing surfaces by helium ion induced swelling: (a) Tilted view dose series of 1 µm diameter circular irradiations on bulk silicon. (b) SRIM simulation of ion stopping range for 15 keV helium ions incident on silicon. (c)(i) A series of circular irradiations with doses ranging from 6×10^{17} to 10×10^{17} ions/cm^2 (ii) Gallium FIB milled cross section views of the same features. (iii) Gallium FIB milled cross section view of a 1 µm circular feature that received 18×10^{17} ions/cm^2. (d) A scatter plot of swelling height for the five features in (c) vs. dose as measured from the FIB milled cross sections.

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